UCRL-TR-210781

LAWRENCE
LIVERMORE
NATIONAL
LABORATORY

Required Be Capsule Strength For Room Temperature Transport

Bob Cook

March 24, 2005

Disclaimer

This work was performed under the auspices of the U.S. Department of Energy by University of California, Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

Target Area Technologies Program

Mail Station L-481

Ext: 2-3117

Date: March 18, 2005

To: Distribution

From: Bob Cook

Subject: Required Be capsule strength for room temperature transport

The purpose of this memo is to lay out the criteria for the Be capsule strength necessary for room temperature transport. Ultimately we will test full thickness capsules by sealing high pressures inside, but currently we are limited to both thinner capsules and alternative measures of capsule material strength.

I will follow the treatment first put in the literature for ICF capsules by Sanchez and Letts.[1] Consider the simple capsule geometry (not to scale) shown in Figure 1.

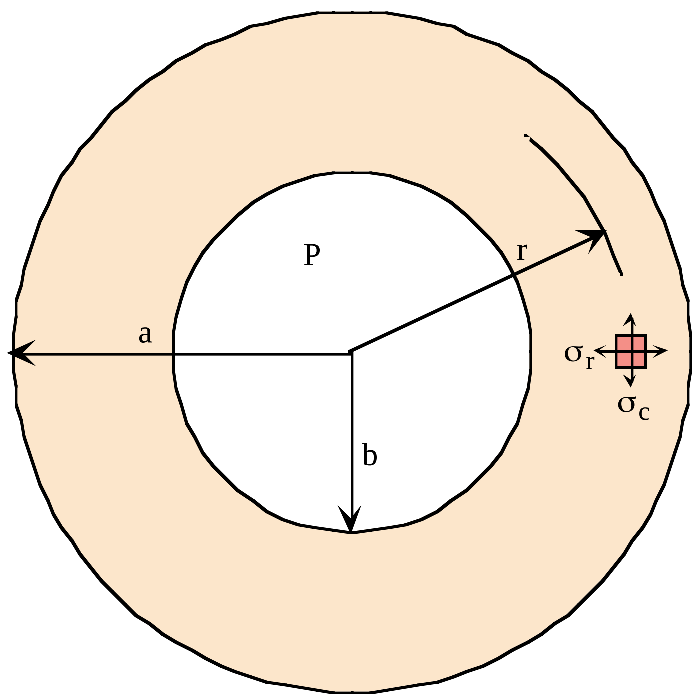

Figure 1. Capsule geometry.

Let the outer diameter be *a* and the inner diameter be *b*. A point inside the wall feels both a radial stress, σ_r, and a circumferential stress, σ_c, due to the pressure P on the inside wall. As a function of the position within the wall r these stresses can be expressed as

[1] J. J. Sanchez and S. A. Letts, *Fusion Technol.* **31**, 491 (1997).

$$\sigma_r = -\frac{Pb^3}{r^3} \cdot \frac{a^3 - r^3}{a^3 - b^3} \tag{1}$$

and

$$\sigma_c = \frac{Pb^3}{2r^3} \cdot \frac{a^3 + 2r^3}{a^3 - b^3} \tag{2}$$

The negative sign on σ_r indicating compressive stress. Both of these stresses are at their maximum on the inner surface where $r = b$; at this point they reduce to

$$\sigma_{r,r=b} = -P \tag{3}$$

and

$$\sigma_{c,r=b} = \frac{P}{2} \cdot \frac{a^3 + 2b^3}{a^3 - b^3}. \tag{4}$$

For our situation the circumferential stress is about 2.7 times as large (in magnitude) as the radial stress. Sanchez and Letts[1] criteria for failure is that the material strength, S, be less than the difference between the circumferential tensile stress, σ_c, and the radial compressive stress, σ_r, or

$$S \leq \frac{P}{2} \cdot \frac{a^3 + 2b^3}{a^3 - b^3} + P = \frac{P}{2} \cdot \left(\frac{a^3 + 2b^3}{a^3 - b^3} + 2 \right). \tag{5}$$

This may be overly cautious. Jeff Klingmann brought to my attention Shigley and Mischke's text *Mechanical Engineering Design* in which data for brittle failure for cast gray iron is presented.[2] The relevant piece of information gleaned from this data is that when there are two essentially independent stresses failure occurs when the limit of only one of them is reached, particularly if the magnitude of one of them dominates. Thus in our case failure would occur when the stresses exceeded the circumferential stress alone, not the sum of the two as indicated in eq 5. This reduces the strength needed by about 25%. Since it is not the point of this analysis to argue over one criteria or another, we will use the more conservative Sanchez and Letts criteria.[3]

Thus in order to operate safely we will require a factor of 2 safety factor, thus the required material strength, S_R, will be

---

[2] J. E. Shigley and C. R. Mischke, *Mechanical Engineering Design, 5th ed*, McGraw-Hill, New York, 1989, p 254.

[3] Steve Deteresa, LLNL, says this is effectively the same as the Tresca yield condition, which for this geometry is the same as the von Mises criterion.

$$S_R = P \cdot \left(\frac{a^3 + 2b^3}{a^3 - b^3} + 2 \right) \tag{6}$$

For the 1.8 and 1.0 MJ designs[4] the outer radii (a) are 1200 and 1000 µm, respectively, and the inner radii (b) are 1010 and 838 µm, respectively. Thus for these designs we have $S_R(1.8\ \mathrm{MJ}) = 7.43P$ and $S_R(1.0\ \mathrm{MJ}) = 7.29P$, about the same. The pressure of the DT gas at room temperature will of course depend on the fill requested, nominally this is an 80 µm solid layer, resulting in a pressure of at most 350 atm. Thus the minimum capsule strength is about 2600 atm or 260 MPa or 38 kpsi.

On a recent tensile test of a 2-mm diameter, 22-µm wall capsule, failure occurred at 11.8 pounds of force, which corresponds to about 51 kpsi, somewhat in excess of our criteria. Burst tests need to be performed on thicker capsules that cannot be tensile tested. However a combination of a refocusing of resources, variations in the deposition process, and perhaps most importantly concern about the viability of a laser sealed design that would have to be built into a target and shot within 36 h to prevent a significant build up of He, has put further strength testing on hold for now.

[4] Steve Haan, LLNL. A published design very similar to thje 1.8 MJ design can be found in S. W. Haan, et al., *Fusion Sci. and Technol.* **45**, 69 (2004).

Distribution:

Craig Alford L-474

Tom Bernat L-481

Bob Cook L-481

Janelle Gunther L-399

Steve Haan L-023

Bruce Hammel L-481

Jeff Klingmann L-481

Steve Letts L-474

Evan Mapoles L-399

Rand McEachern L-377

Mike McElfresh L-481

Jorge Sanchez L-481

Russell Wallace L-481

Neil Alexander GA

Jason Cooley LANL

Abbas Nikroo GA

Art Nobile LANL